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NOTES ON THE PROGRESS OF DOUBLE-STAR
ASTRONOMY.*

BY WILLIAM J. HUSSEY.

It is nearly a hundred years since Sir WILLIAM HERSCHEL, as a result of the comparison of measures which he had just obtained with others made by him some twenty years earlier, was able to announce half a dozen cases in which he had found one star revolving about another. At that time this was a wonderful discovery. Astronomers had not expected to find suns moving in this manner, and it is not surprising that they were amazed when HERSCHEL proved this to be the case by producing such an array of facts and arguments that no room was left to doubt the correctness of his conclusions.

Previously but little attention had been given to the stars for their own sakes. With instruments such as were in use, perhaps it was thought that not much of interest could be ascertained concerning them. As reference-points in the sky they had been of use (and are so still) in facilitating the investigations of the motions of the bodies composing the solar system, and it does not appear to have been imagined that there is great variety among them. HERSCHEL'S discovery was one of the factors which have operated to change all this. He showed that the stars are not all after the same pattern, but that they have their several stories to tell to those who will interrogate them properly, and ever since his time astronomers have more and more been finding this to be the case. New departments of sidereal investigation have come into existence. Besides all that relates to the absolute positions and movements of the stars as determined by the meridian observations, and those relative changes which are ascertained from the micrometrical measures, there are the extensive fields of research in which are considered those strange variations of light exhibited by certain of the stars, and the multiplied diversity of phenomena which have been revealed by the study of stellar spectra. With larger telescopes, more efficient subsidiary apparatus, more exact theories of instruments and

* This article does not pretend to cover the entire field of double-star astronomy. It gives no account of the numerous determinations of orbits which have appeared from time to time, and nothing concerning spectroscopic binaries of which quite a number have recently been discovered.

methods, and a greater number of enthusiastic investigators, results of greater variety and ever-increasing interest and importance are being obtained. In this rapid movement forward which now characterizes sidereal astronomy, that part which relates to double stars, visually considered, follows methods which have been in use for many years, and it appears probable that this will continue to be the case for all of the more interesting systems.

The number of stars which have been catalogued as double and multiple has reached the formidable aggregate of over thirteen thousand. The majority of these are the discoveries of long ago. The catalogues of the HERSCHELS and the STRUVES alone contain more than nine thousand entries. But many of these are wide and easy pairs, whose components sustain no known physical relation to each other, and which are of such a character that were they now found for the first time no one would think of cataloguing them as double stars.

For nearly forty years, dating from 1782, Sir WILLIAM HERSCHEL was almost the only observer of double stars. Eight hundred and twelve of those which he observed have been identified. Many of these were his own discoveries, and all of the more important ones were included by STRUVE in the Dorpat Catalogue.

Sir JOHN HERSCHEL began his long career in astronomy in 1816 by taking up, under his father's direction, the re-examination of all the double stars discovered by him. By a fortunate circumstance, he worked from 1821 to 1823 in conjunction with Sir JAMES SOUTH, at the latter's private observatory in London. This was provided with two telescopes of very modest dimensions according to our present standards. One was three and three-quarters and the other five inches aperture. With these little instruments, not supplied with driving-clocks, these observers made a series of observations of 380 double stars, which is remarkable for the skill, patience, and accuracy with which it was executed, and for the confirmation of the phenomena first brought to light by Sir WILLIAM HERSCHEL.

These observations of SOUTH and HERSCHEL were published in the *Philosophical Transactions* for 1824, and won for them the Lalande Prize of the French Academy in 1825, and gold medals from the Royal Astronomical Society in the following year. At the same time this society presented its gold medal to WILLIAM

STRUVE for the double-star observations which he had made at Dorpat, and made honorable mention of the work of AMICI at Modena in the same direction. These four were the only double-star observers then living.

Previous to this time STRUVE had been using a very modest telescope in his double-star work. But in 1824 FRAUNHOFER completed for the Dorpat Observatory the celebrated refractor of nearly nine and a half inches aperture. This was equatorially mounted, and provided with a good driving-clock. For fifteen years it remained the largest refractor in the world, and during that time it was by far the most efficient telescope in existence for double-star work.

On receiving this equatorial, STRUVE resolved to reobserve all the double stars then known from the north pole to 15° South Declination, and to examine carefully all the brighter stars within this region for the purpose of discovering new pairs. In the course of this survey he is said to have examined no fewer than 120,000 stars. As a result of the first two years' work upon this programme, he published in 1827 the Dorpat Catalogue of 3,065 double and multiple stars. In this were included not only his own discoveries, but also all other objects which had been found by other astronomers within 105° of the north pole, and which appeared to him worthy of being called double stars.

The second part of STRUVE's programme was more arduous and required a greater time. To obtain exact micrometrical observations of all the double stars of the Dorpat Catalogue which are worthy of attention is no small undertaking, and it is surprising that STRUVE accomplished it in the comparatively short interval of twelve years. In 1837 he published the "*Mensuræ Micrometricæ*," a ponderous folio, containing the observations made at Dorpat with the large equatorial from 1824 to 1836, together with the results which he had obtained with a smaller instrument from 1813 to 1824. It also contained many of the observations by the HERSCHELS and SOUTH, so that it may be said that this volume gave all that was known at the time of its publication concerning the double stars of the Dorpat Catalogue. When the objects of this catalogue came to be critically examined, it was found that some had distances greater than $32''$, which was the maximum limit set by STRUVE; that some were not double; that some were identical with others, erroneous positions having been assigned to them. For these and various

other reasons 492 were rejected, or about sixteen per cent. of the entire number.

About 1827, Sir JOHN HERSCHEL began a series of "sweeps" with large reflecting telescopes, which resulted in the discovery of large numbers of nebulae and 5,533 double and multiple stars. Some of these are in the northern and some in the southern hemisphere. Many of these double stars have little claim to be called such, consisting, as they frequently do, of wide pairs of faint stars. Many of them have not been measured since their discovery, and even at that time the angles alone were measured, the distances were estimated. Taken as a whole, they are of little consequence, except that they swell enormously the number of objects listed as double stars.

In 1839 the great Russian Observatory at Pulkowa was established, and WILLIAM STRUVE was called from Dorpat to be its first Director. Its largest instrument was the 15-inch refractor. With this, in 1841 and 1842, OTTO STRUVE examined all the brighter stars north of the equator, and by doing so discovered a large number of close and difficult double stars. His first catalogue contains 514 objects, which subsequent discoveries increased to 547. In this catalogue it was intended that the distances should all be less than $32''$, and the magnitude of the principal star, or the combined magnitude of the two in the case of close doubles, not to descend below 7.8. As companions all stars at distances less than $16''$ and bright enough to be readily measurable with the 15-inch telescope were admitted, while for distances between $16''$ and $32''$ the limiting inferior magnitude was 8.9. When the stars came to be measured, it was found that some fell outside of the limits just described, and for this and other reasons 106 of the objects enumerated in the first edition of the Pulkowa Catalogue were rejected.

Sir WILLIAM HERSCHEL'S work on double stars had begun in his attempt to find suitable pairs of stars for the determination of stellar parallaxes. Having satisfied himself that in these investigations the method of double stars would have many advantages over any other, he states that he resolved to examine every star in the heavens with the utmost attention and with a very high power, in order to ascertain what stars are best suited to this research, so that he might make his observations on those that promised the best results.

We have noted that WILLIAM STRUVE examined no less than

120,000 stars within 105° of the north celestial pole with the Dorpat refractor, for the express purpose of discovering those which are double. Sir JOHN HERSCHEL swept both the northern and the southern heavens in quest of double stars and nebulae. Finally OTTO STRUVE made the Pulkowa refractor famous by reason of the large number of difficult double stars which he discovered with it, in the course of his examination of all the brighter stars in the northern sky. After all of these examinations by experienced observers armed with powerful telescopes, it is no wonder that the astronomers at the middle of the nineteenth century were disposed to think that all or nearly all of the interesting double stars had already been discovered, and that what remained to be accomplished in this field was to continue the observation of those already known and to compute the orbits of the binaries whenever the data for the purpose became sufficient. For thirty years following the publication of the Pulkowa Catalogue very few double stars were discovered. During this time, however, some remarkable series of observations were obtained. To this period belong the observations by OTTO STRUVE, MADLER, DAWES, SECCHI, and DEMBOWSKI, not to mention others. Their observations have served to determine the character of the motion, where any is shown, in the great majority of the stars contained in the Dorpat and Pulkowa catalogues; and if the information which is now scattered through many publications were brought together and printed in convenient form, the astronomers of the future would have but little difficulty in ascertaining what further attention, if any, is desirable in the case of any of the double stars contained in these extensive catalogues. Such publication of the data now available would most effectively advance the interests of this department of astronomy, by practically removing from consideration the large numbers of these stars which have shown little or no motion, and explicitly pointing out those which are in need of further attention.

The revival of the discovery of double stars dates from 1873, when BURNHAM began to publish accounts of those which he found with his 6-inch telescope at Chicago. In this year he published three catalogues in the *Monthly Notices* of the Royal Astronomical Society, announcing 182 new double stars. Since that time discovery has proceeded rapidly, as is shown by the following summary, which gives approximately the numbers of

NEW DOUBLE STARS DISCOVERED BY VARIOUS
OBSERVERS SINCE 1870.

BURNHAM.....	1,290
HOUGH	623
SEE	500
INNES.....	305
Cincinnati Observatory observers.....	181
Washburn Observatory observers.....	171
Harvard and Arequipa observers.....	109
HUSSEY	100
AITKEN	47
Miscellaneous, perhaps about.....	200
	<hr/> 3 526

This list does not profess to be complete. It is merely intended to indicate the large number of discoveries which have been made during the past thirty years. It is well known that several observers have recently found considerable numbers of new double stars which are still unannounced.

The double stars of the lists above include a great majority of the closest and most difficult pairs known, and a large number of rapid and interesting binaries. Professor BURNHAM's discoveries alone include 690 pairs having distances not exceeding 2'', while there are only 680 such pairs among the more than nine thousand double stars that had been catalogued before 1870. The discovery of so many close and difficult stars has added enormously to the labor in this department of astronomy, but this has its compensation in the rapid increase in the number of known physical pairs, and in the important additions to our knowledge respecting them.

These circumstances have given the subject a greater interest. The number of observers has increased somewhat, but hardly in proportion to the increased number of instruments available for such work, and the literature has become much more extensive and scattered than formerly. This state of affairs has both advantages and disadvantages. A greater number of observers insures more measures, a less likelihood that important pairs will long be overlooked, and more complete data for the determinations of orbits, and of systematic and accidental errors of observation. But, on the other hand, the observations are being scattered through a great variety of publications, and it has become an exceedingly difficult matter for the average observer to ascertain what stars have already received sufficient attention and what

ones should be kept on the observing list. In most cases it is far easier to make a new set of observations of a given star than to examine the literature thoroughly to see whether such observations are needed. Any additions, therefore, to the works which collect and classify the material already available in this department of astronomy makes for progress, and it is a pleasure to note that two such books, both of great importance, have recently appeared. The first volume of the Publications of the Yerkes Observatory is "A GENERAL CATALOGUE OF 1,290 DOUBLE STARS DISCOVERED FROM 1871 TO 1899 BY S. W. BURNHAM," and Part II of Volume II of the Annals of the Royal Observatory, Cape of Good Hope, is a "REFERENCE CATALOGUE OF SOUTHERN DOUBLE STARS, BY R. T. A. INNES."

Professor BURNHAM has given an excellent statement of the needs which led to the preparation of his General Catalogue in the opening words of his introduction, as follows:—

"A general catalogue of all the double stars discovered by me from time to time during the past twenty-five years has long been needed by those interested in this field of astronomical research, and, by reason of the special interest attached to many of these remote sidereal systems, it has become more and more important to bring the scattered material together in order to intelligently pursue the investigations which promise to so much increase our knowledge of the great universe beyond the solar system. These discoveries are scattered through nineteen different catalogues, published at various times and places, commencing with 1873; and the observation of these stars by a great number of astronomers in this country and in Europe can only be made use of by consulting hundreds of volumes of observatory and society publications, astronomical periodicals, etc. It is difficult, if not practically impossible, for the general observer or investigator to make a really complete collection of all the measures of a large number of these stars. Many of the observations are in obscure and unusual places, and in works not always readily accessible."

Professor BURNHAM'S General Catalogue covers its ground very completely; and not only in the arrangement of its material, but also in its typographical effect, it is a model of excellence which may well be followed in other books of a similar character. It gives a record of all the double stars discovered by BURNHAM through a long series of years. Nothing essential to their histories is wanting, and nothing superfluous added. The stars are arranged in the order of Right Ascension. The mean results of all the observations of each pair are given in chronological order. These are followed by notes of such length as may be needed to

give an account of the discovery, the character of the pair, the circumstances of its motion, and any other facts of interest or importance concerning it. Diagrams are freely used to illustrate the motions of the more interesting cases. Finally, each pair is accompanied by references to all the original sources of information.

It is not likely that the importance of this work will be overestimated. Having it at hand, it will generally be possible to see at a glance, from the data which it contains, whether the components of any given pair are in motion or not, and thus the future observer may readily select from among these stars those which are needing observation and which are likely to lead to interesting results. Moreover, this selection will be the more easy, for Professor BURNHAM has given a provisional list of 185 pairs which have already furnished more or less evidence of being physical systems. Some of these are rapidly moving binaries. The orbits of eight have already been computed. These include κ *Pegasi* whose period (11.42 years) is the shortest known among the visual binaries.

In the introduction to his volume Professor BURNHAM has given a brief history of the beginning of his astronomical career. Since this is of very general interest, I quote a portion of it, as follows:—

“When in London, about 1861, I purchased one of the cheap astronomical telescopes introduced about that time. It had a nominal aperture of three inches, but was without a finder, and had only the simple altazimuth mounting, with a common table tripod. It was supplied with a terrestrial as well as astronomical eye-piece, and while it was a good instrument for landscape use, it was of little value for astronomical purposes. Some years later I obtained a $3\frac{3}{4}$ -inch telescope, with an English object-glass, mounted equatorially by FITZ on a portable stand. This was just good enough to be of some use, and poor enough, so far as its optical power was concerned, to make something better more desirable than ever. In 1869 I accidentally met Mr. ALVAN G. CLARK in Chicago on his return from Iowa, where he had been to observe the total eclipse of that year, and made some inquiries of him concerning a small equatorial. The interview resulted in my ordering from the celebrated firm of ALVAN CLARK & SONS an equatorial of six inches aperture. I told them what I wanted and what I wanted it for. Every detail was left entirely to their judgment, stipulating only that its definition should be as perfect as they could make it, and that it should do on double stars all that it was possible for any instrument of that aperture to do. In due course of time this instrument was delivered, and was set up in an observatory prepared for it in the mean time. My attention, for

some reason or other which I am unable to explain, had been almost exclusively directed to double stars previous to this while using the smaller telescope referred to. This preference was not in any sense a matter of judgment as to the most desirable or profitable department of astronomical work, or the result of any special deliberation upon the subject. It came about naturally, without any effort or direction upon my part."

By adhering to this one line of astronomical work, becoming familiar with its extensive literature, and by a still more effective examination of the sky, Mr. BURNHAM has attained a more complete mastery of this department of astronomical work than any other man has done. All of the double stars discovered by him have been found with telescopes having objectives by ALVAN CLARK & SONS. Over eight hundred of his discoveries were made in Chicago, and nearly three hundred at the Lick Observatory. Their distribution among the several telescopes, which he used at various times, is given as follows:—

6-inch—Private Observatory	451
18½-inch—Dearborn Observatory	413
36-inch—Lick Observatory	198
15½-inch—Washburn Observatory	87
12-inch—Lick Observatory	56
9.4 inch—Dartmouth College Observatory	24
26-inch—U. S. Naval Observatory	14
40-inch—Yerkes Observatory	8
16-inch—Warner Observatory	2

The gold medal of the Royal Astronomical Society was awarded to Mr. BURNHAM in 1894 for his double-star discoveries and investigations.

Comparatively little has been done upon the double stars of the southern hemisphere, and until the appearance of Mr. INNES's book no general catalogue of them had been published. Hitherto, observers desiring to work in that field had three courses open to them: they could spend their time in searching for suitable objects in the sky, or they could confine their attention to those in the vicinity of the equator which generally had been discovered by northern astronomers and measured by them, or they could search through many publications to ascertain what southern stars were in need of attention and likely to lead to interesting and valuable results.

Mr. INNES has done much to remove the difficulties which have confronted observers, and his book cannot fail to have a

wide influence in stimulating the study of the double stars situated in a region heretofore considerably neglected. He has given descriptions of about twenty-two hundred double stars belonging to the southern hemisphere. These are arranged in the order of Right Ascension. Each pair is accompanied by a selection of the micrometrical measures which have been made upon it, and from these it is frequently possible to form an idea respecting the state of rest or motion of the components. Notes are sparingly used, and usually relate to questions of motion, magnitudes, etc. Except in a few cases, such as *Sirius* and α *Centauri*, references to original sources of information are not given in connection with each pair, but at the end of the volume we find an extensive list of books and papers "chiefly limited to treatises of general interest or such as contain observations of southern double stars."

Mr. INNES has deemed it impracticable to include in his catalogue all the objects of the southern hemisphere which at one time or another have found their way into the lists of double stars. In order to have a criterion for the rejection of undesirable pairs, he has adopted the scale of limiting distances according to magnitude given in the following table:—

Magnitude of Primary.	Limiting Distance of Components.
1	30''
2	25
3	20
4	15
5	10
6	7
7	5
8	3
9	1

In the beginning it would no doubt have been better if the limits as to distance had been more restricted, and if large numbers of wide pairs had never been catalogued. But it is difficult effectively to remove a star which has appeared in the lists; and however much we may regard the action of Mr. INNES in restricting the distances to narrow limits as a move in the right direction, we still have a lingering wish that he might have

included all known pairs in his book. At times he has found it necessary to set aside the limits which he has adopted. This has been done in order to retain "many wide pairs, worthy of inclusion from some point of view." Among these are "some systems much exceeding the above distances and showing no certain signs of orbital motion," but which have been retained "on account of large proper motion common to both components." But perhaps the most serious objection to the general adoption of the above scale of distances is, that the limits for the fainter magnitudes are so narrow that some of the northern binaries would be excluded, and it is not impossible that this may also be the case with some of those of the southern hemisphere. The companion to μ *Herculis* is an example. The magnitudes of the components of this pair are 9.4, and 10, and the period in which they complete a revolution is about forty-five years. According to my measures with the thirty-six-inch refractor, the distance last year was 1".54. The last star in the Pulkowa Catalogue, O Σ 547, is another example. The magnitudes in this case are 8.3 and 8.3, and in 1898, the distance which I obtained as a result of three nights' measures was 4".62. Not only do these stars have a common proper motion of nearly a second a year, but from the time of the first micrometrical observations the position-angle has been increasing about three fourths of a degree per year without appreciable change of distance.

In the various double-star catalogues are to be found many pairs consisting of a bright star and a distant faint companion. The distance between the components of many of these pairs is so great that they would now probably be considered unworthy of attention by any one looking for new double stars. In some cases these pairs have exhibited changes in position-angle and distance, which may be traced to the difference of the proper motions of the two stars, but the majority have shown no certain change in the relative positions of their components during the period over which the micrometrical observations extend. Nevertheless, among these pairs are many examples in which the proper motion of the principal star has been determined from meridian observations, and found to be so large that a marked change in position-angle and distance would take place in a comparatively short time, were it not that the companion has the same proper motion as the principal star. These cases are so

numerous that they cannot be ascribed to fortuitous circumstances, and we are compelled to admit that the stars which are moving together in this manner are physically related. How wide may be the limits over which this physical connection extends no one at present can tell. The photographs of large nebulae frequently exhibit arrangements of stars which so closely conform to the nebular outlines as to afford some evidence that the stars and nebula are physically associated. A nebula may cover a large area, but however extensive it may be, we entertain no doubt as to the physical connection of its various parts. With some reason, then, we may also assume a possible physical relationship of the stars which appear to be associated with it. If this be granted, we have at once a far wider limit of apparent distance than has been admitted in any of the extensive catalogues of double stars.

The considerations just given do not afford an argument of any particular force in favor of including additional wide pairs in future catalogues of double stars. It may be well to retain those which have been micrometrically measured at various epochs, and to obtain occasional additional observations of them in the future; for it may be that these measures will eventually furnish some valuable information concerning the motions which are slowly taking place among these distant sidereal systems.

But there appears to be no sufficient reason for adding to their number, as would be an easy matter with the large telescopes of the present time. On the contrary, in the case of new discoveries, there is a decided tendency to adopt limits only a little wider than is necessary to include the known binaries, to the end that the number of objects to be considered may not become unmanageably large, and that the lists may have an average higher interest. Besides, there is another consideration. Large distances can be obtained more accurately from the measurement of large-scale photographs than directly with the micrometer. On this account it is not inappropriate to leave the wide and easy pairs for photographic measurement.

The attempts which have been made to obtain the position-angles and distances of moderately close and unequal pairs through the medium of photography cannot be said to have been attended with much success, either when we consider the number of measures obtained or the character of the pairs. The photographic method has its limitations. These are such as render it worthless in investigations relating to the closest and most diffi-

cult double stars, which are the ones that include all of the rapid binaries. In this field of work the visual and the photographic methods are not competitors. The reason is simple enough. The eye can see as double what the photographic plate, used in an instrument of practicable dimensions, would certainly record as single. The images of the components of a close double star as formed by the objective of the telescope are very near each other. Thus, the scale for the 12-inch telescope of the Lick Observatory is $1/1100$ th of an inch to 1", and that for the 36-inch refractor $1/297$ th of an inch to 1". Under the most favorable circumstances the eye is able to detect the elongation produced by the partial overlapping of equal stellar images when their centers are not more than $1/5000$ th of an inch apart. The photographic plate does not possess resolving power to this extent. The silver grains in the film have dimensions probably twice as large. Besides, for objects such as double stars, photographic images not larger than the silver grains cannot be realized. The light spreads through the film, the area over which the photographic action extends becomes enlarged, the image of a bright star obliterates that of its faint companion, and in the case of close and equal pairs the images of the two components are merged together and lose their identity.

MT. HAMILTON, CALIFORNIA, May 29, 1900.

THE ORBIT OF *T CYGNI*. (A. G. C. 13.)

BY R. G. AITKEN.

The companion to *T Cygni* was discovered by ALVAN G. CLARK in October, 1874, with the 26-inch telescope now mounted at the Leander McCormick Observatory. The first measures were secured in the same year by NEWCOMB, with the 26-inch refractor of the Naval Observatory, and by DEMBOWSKI, with an instrument of only seven inches aperture. The latter observer demonstrated the existence of relative motion in this system by his measures during the few years following discovery, and it soon became apparent that this motion was orbital. Other observers also gave the pair attention until 1880; but from that year until 1889,